APPENDIX 5.5A
Reconnaissance Geophysical Survey Report

FINAL REPORT

Geophysical Investigation of the Mission Bay Landfill in San Diego, California

Submitted to:

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1. INTRODUCTION

3Dgeophysics.com (3Dg) performed a geophysical investigation at the Mission Bay Landfill (MBLF) site (the "site"), located in San Diego, CA. The geophysical investigation consisted of two methods; a high resolution gradient magnetometry survey and three (3) ground conductivity profiles. The geophysical study was completed under the authorization of Ms. Karen Stackpole from SCS Consulting Engineers, Inc. (SCS). Written authorization to proceed was provided by SCS on April 29, 2004. The fieldwork began on May 21 and concluded on May 26.

The objective of the geophysical investigation was to map the occurrence of ferrous metal within the landfill, to help delineate the boundaries of the landfill, and to help identify potential infiltration that may occur where groundwater flows from the San Diego River Channel to Mission Bay along the former course of the San Diego River. The results of th study will be used to help determine the environmental management alternatives at the site.

The location of the site is shown on a road map in **Figure 1**.

2. METHODOLOGY

The geophysical investigation consisted of two geophysical techniques including gradient magnetometry (MAG) and electromagnetic ground conductivity mapping (EM). A Differential Global Positioning System (DGPS) was integrated with the geophysical equipment and used for position control during the MAG and EM surveys. **Table 1** summarizes the methodology and instrumentation used for the investigation. **Figure 2** shows the locations of the geophysical surveys on a 2002 aerial photograph of the site.

TABLE 1: METHODOLOGY & DATA ACQUISITION EQUIPMENT

Method	Instrument	Specifications
Gradient Magnetometry	Geometrics 858	Cesium Vapor Differential (2 sensors)
Ground Conductivity mapping	Geonics EM34	Model EM34-3XL
Surveying	Trimble GPS	Model Ag-114 Differential (OmniStar enabled)

2.1 GRADIENT MAGNETOMETRY

The purpose of the MAG survey was to provide a high resolution map of buried metal objects such as drums at the site. The results of MAG survey will be used to help delineate the landfill boundaries.

The MAG data were collected using a Geometrics, Inc. Model 858 cesium vapor magnetometer. Two magnetometer sensors, separated by 1 meter, were used to collect gradient (differential) MAG data. The magnetometer measured the localized distortions in the magnetic field of the earth caused by magnetic objects like buried steel tanks, drums, containers, and other debris. **Figure 3** shows an illustration of the theory of operation of the magnetometer. For more detailed technical discussions of magnetometer operation, data collection methods, and data interpretation please refer to Breiner (1999), Smith (1997), Dobrin (1960), and Parasnis (1962).

A non-magnetic and non-conductive instrument trailer and a utility vehicle equipped with turf saver tires data were used to collect the MAG data. An OmniStar enabled DGPS with sub-meter accuracy (Trimble Ag 114) was connected directly to the magnetometer to provide position control for each of the magnetometer readings. Accuracy and reliability of the DGPS system was subject to anomalies such as multipath, obstructions, satellite geometry, and atmospheric conditions. DGPS surveying conditions at the site were excellent. As many as 11 and no fewer than 8 satellites were visible to the GPS receiver during the survey (only 5 satellites are required for DGPS measurements). The X and Y position output from the DGPS and logged by the magnetometer was within 1 meter of actual position. **Figure 4** shows a photograph of the data acquisition system used for the MAG survey.

The boundaries of the study area were provided by Ms. Karen Stackpole (SCS) to 3Dg prior to the fieldwork. GIS software (HGIS, StarPal, Inc.) was then used to overlay the study area perimeter on a geo-referenced aerial photograph of the site. A 100 x 100 ft survey grid was then generated over the study area using the defined perimeter. Data collection required driving the utility vehicle and instrument trailer across the site according predefined survey grid. A handheld PC running the HGIS software was mounted to the utility vehicle and the aerial photograph with the survey grid overlay was used to navigate across the site. The data acquisition system was driven along the 100 ft survey grid lines until the entire survey area was sampled. Special care was taken to avoid cultural features and sensitive environmental areas on the site. MAG data collection deviated from the predefined survey grid in these areas. **Figure 5** shows a map of the MAG data points collected during the survey.

The magnetometer data was collected using a data point spacing with sufficient spatial sampling to resolve the important buried metal objects. MAG data were collected with a 10 Hz sampling frequency (10 samples/second). The average density of the MAG data along the data collection lines varied from approximately 0.3 – 1.0 samples per linear foot. The data were not collected during a solar storm or during large fluctuations in the magnetic field of the earth. Because gradient magnetometer data were collected, recording of diurnal field variations was not required. **Table 2** summarizes the surface elevation mapping parameters.

The MAG survey was complicated by the cultural features on the surface of the site. MAG data are extremely sensitive to surface metal and other utilities. In areas with large amounts of surface metal and clutter, such as the Sea World parking lot, the data acquisition system was driven in a manner to minimize potential interference between the visible surface metal and the magnetometer sensors. The Sea World parking lot contained vehicles, construction cranes, construction contractor trailers, and light poles, although the data acquisition team tried to avoid getting too close to these magnetic objects. Also, in areas of the site with high vehicle or foot traffic, the MAG data were collected in the early morning or at night to avoid interference from parked or passing vehicles.

Errors were encountered in one of the magnetometer sensors during a portion of the survey. Where the errors existed gradient values could not be calculated. However, the error zone was small in areal extent and represented less than 4% of the total survey area. Total field MAG data (MAG data from 1 sensor only) were collected where the gradient values could not be calculated. Figure 5 shows where the total field data were acquired. The total field data were preprocessed after data collection so the total field data could be integrated with the gradient data to produce a continuous map of the survey area. An average field value was calculated for the affected magnetometer sensor using the samples in the data file directly before and after the errors were encountered. This average value was then subtracted from the second magnetometer sensor readings, which did not have errors, to generate gradient field values from the total field data. It is important to note that total field data are equally sensitive to buried metal objects as gradient data.

After the field work was completed the geo-referenced MAG data were processed using MagMap2000 (Geometrics, Inc.) software and a PC workstation. The data were filtered, edited, smoothed, and then interpolated into a regular grid and plotted using the Surfer v8.03 surface mapping software program (Golden Software, Denver, CO). A Kriging routine was used to interpolate the data, and the data were contoured with minimal smoothing to minimize affecting the high frequency data. Because the objective of the work was to map buried metal objects, and not geologic formations, 'reduction to pole' and other advanced magnetic data processing techniques were not viable.

For the project data quality control was maintained in several ways. The data collection equipment was calibrated by the manufacturer prior to use on the project. The National Weather Service was consulted prior to the beginning of data collection to insure that the survey was not conducted during a solar storm. All field recording parameters, and any changes to parameters during data collection, were fully recorded each day and for each data file by the field crew manager / instrument observer. After each day of data collection the raw data were reviewed for quality control and archived on a personal computer. In addition the processed data plots were reviewed by comparing the results to site features and terrain, existing site photographs, and the locations of known noise sources.

TABLE 2: MAGNETOMETRY DATA COLLECTION PARAMETERS

Parameter	Value
Operation Mode	Gradient (Differential)
Sensor Separation	1 meter
Sampling Interval	10 samples/sec
Data Points	212,033
Inline Data Density	0.3 – 1.0 samples/ft
Approximate Survey Size	9,334,000 sq ft (867,200 sq meters)

2.2 EM GROUND CONDUCTIVITY SURVEYS

An electromagnetic (EM) conductivity survey was used to map the electrical properties of the subsurface sediments at the site. Clayey materials, saturated sediments, and saline groundwater are generally electrically conductive, while sandy, dry materials, unaltered bedrock, and freshwater are generally more resistive. The purpose of the EM survey was to potentially map a buried river channel and possible fresh water infiltration features in the subsurface at the site.

The EM data were collected using a Geonics, Ltd. EM34-3XL ground conductivity meter. The EM34 system measures the localized magnetic fields caused by eddy currents induced in the subsurface sediments. The current flow in the sediments is induced by a primary EM field which is generated by a transmitter coil of the EM34 system. A receiver coil of the EM34 then measures the resultant field at a fixed offset from the transmitter. The amplitude and phase shift of the EM field at the receiver is directly related to the conductivity of the ground in which the field was generated. The separation distance between the transmitter and receiver is varied to generate conductivity values at different depths in the subsurface so that geo-electric cross sections can be created. **Figure 6** shows an illustration of the theory of operation of the EM34 ground conductivity meter. For more detailed technical discussions of EM ground conductivity instrument operation, data collection methods, and data interpretation please refer to Geonics, Ltd. (1980a), (1980b) and (1980c).

Figure 7 shows a photograph of the data acquisition system used for the EM survey. The instrument trailer used for the MAG survey was modified to house the EM34 system electronics and receiver coil. A non-conductive sled was constructed to hold the EM34 transmitter, which was towed behind instrument trailer. The DGPS was connected directly to the EM34 system to provide position control for each of the EM profiles. Based on the recommendations of the instrument manufacturer and the data processor, PetRos EiKon Incorporated (Concord, ON, Canada), the EM data were collected using the EM34 system in the vertical dipole configuration.

Three EM profiles were collected for the investigation. The approximate locations of the EM profiles in the study area were also provided by SCS prior to the fieldwork. The line locations were identified on the site by approximating the positions using an aerial photograph. The lines were adjusted slightly to avoid cultural features and environmentally sensitive areas on the surface of the site. Survey stakes and flags were used to mark the endpoints and site lines for each profile.

Data collection required driving the utility vehicle, instrument trailer, and transmitter sled along the profiles. Data were collected three times along every profile; once for each transmitter-receiver separation distance (10, 20, and 40 meters). To facilitate data processing and the generation of geo-electric sections from the data, data collection along each profile began and ended at the center point between the EM34 transmitter and receiver. The locations of each of the EM34 profiles is shown on an aerial photograph of the site in Figure 2. The EM34 data were collected with a 5 Hz sampling frequency (5 samples/second). Although the rate of sampling remained constant, the data density (samples/ft) varied with the speed of data collection. It is important to note, however, that the small differences in data collection speed were corrected during data processing. **Table 3** summarizes the ground conductivity mapping parameters.

After the field work was completed, the EM34 data were delivered to PetRos EiKon Inc., which was contracted by 3Dg to process the EM data. Dr. Ross W. Groom, PhD performed the data processing using EMIGMA EM data processing and inversion software that was developed by PetRos EiKon, Inc.

A complete list of the digital processing steps that were applied to the EM34 data is provided in **Table 4**. To optimize the survey results the data were analyzed multiple times using forward modeling exercises, and two different data inversion techniques were applied to the profiles (Marquardt and Occam inversions). Great care was taken to maintain the integrity of the data and to verify the results after each stage of the data processing. The EM34 data processing steps, including the data inversion techniques, are described in more detail in **Appendix A**.

After the data were processed the geo-referenced data from each profile were then interpolated into a regular grid and plotted in a color-contoured cross section using the Surfer surface mapping software program.

TABLE 3: GROUND CONDUCTIVITY DATA COLLECTION PARAMETERS

Parameter	Value
Dipole Orientation	Vertical
Transmit Power	High
Sampling Interval	5 samples/sec
Dipole Separation	10, 20, 40 meters
No. of Samples/Line	38,582 (Line 1) 87,577 (Line 2) 81,348 (Line 3)
Approximate Survey Size	1165 ft (Line 1) 885 ft (Line 2) 2410 ft (Line 3)

TABLE 4: EM DATA PROCESSING SEQUENCE

Processing Steps
Data Conversion (Instrument binary to ASCII) Coordinate Conversion (Lat/Long to UTM) GPS Offset Correction Position Correction/Editing Merge Datasets per Profile (10, 20, 40 m) Interpolate & Smooth Data for Position Alignment Edit Data (QA/QC - remove offline effects) Decimate Data to Original Sample Interval (Gaussian averaging) Smooth Elevation Data Forward Modeling (determine gross geologic structure) 1D Data Inversion (resistivity-depth calculation) Occam inversion (over parameterized, unconstrained) Marquardt inversion (layer model, constrained) Gridding Statics Correction X,Y,Z Data Output

3. RESULTS

3.1 MAGNETIC DATA

The MAG data were collected along grid lines spaced approximately 100 ft apart over an approximate 9,334,000 square-foot area of the site. Figure 5 shows the data coverage map for MAG data. After the data set was processed the data were gridded with an interpolation algorithm and contoured using the Surfer surface mapping software program.

Since magnetic anomalies created by buried metal objects are much smaller than the natural earth field, the gradient magnetic method was used for the investigation. Two magnetometer sensors, arranged vertically and separated by 1 meter, were used to collect the data. Since magnetic field strength at a point, caused by a dipole, varies as the cubed distance (d^3) away from the source, the magnetic field of the earth will remain relatively constant over short distances. With the gradient method the recorded values from one sensor are subtracted from the other to remove the influence of the earth field and to isolate the localized magnetic anomalies causes by buried metal objects.

Figure 8 shows the MAG data contoured on an aerial photograph of the site. Gradient magnetic readings range from 3300 to -4500 gamma across the site. The map uses color-filled contours to display the data. Positive magnetic anomalies are shaded white, red, orange, and yellow while negative anomalies are shaded blue, purple, and black. The green colored MAG values are near 0 gamma and represent the baseline of the dataset. The contour interval on the map is 100 gamma.

Magnetic anomalies (both positive and negative) are prevalent across the site. The MAG data were reviewed with an emphasis on locating positive and negative anomaly pairs that may represent buried metallic objects. Many anomaly pairs are evident in the MAG map (Figure 8) that may warrant ground truthing. It appears, however, that some of the magnetic anomalies follow the trend of the paved roads in the survey area (Sea World Dr., Friars Rd, and the marina road). In addition, some of the magnetic anomalies may be caused by surface features such as light poles, sprinkler systems, and utility boxes. If the magnetic anomalies shown in Figure 8 cannot be correlated with features at the surface of the site or buried utilities then they are interpreted to represent buried metal objects that are most likely related to previous landfill activities.

It should be noted that overlay of the magnetic data on the aerial photograph of the site is an approximation. The site photograph was not available in a format compatible with 3Dg's GIS software so the photograph was geo-referenced using a best-fit match with site features such as the roads and the waterfront. The magnetic anomalies can be located precisely on the site using a field GPS.

3.2 GROUND CONDUCTIVITY DATA

Three EM34 profiles, totaling 4,460 linear feet on the surface of the site, were collected for the investigation. Data were collected three times along every profile with transmitter-receiver separation distances of 10, 20, and 40 meters. During data processing the 3 datasets for each profile were combined to create a geo-electric cross section below the profiles. Figure 2 shows the location of the EM34 profiles on the site.

Figures 9 - 11 show the EM34 profiles. The data plots are color-coded contour maps of the ground resistivity beneath the profile. As per convention, the ground conductivities, measured in the field in millisiemens/meter (mS/m), were converted to resistivities in Ohm-meters during data processing. Resistivity is the reciprocal of conductivity. High resistivity (low conductivity) areas are shaded red, orange, yellow and green, while low resistivity (high conductivity) areas are shaded blue and purple in Figures 9 - 11. The x-axis of the figures show distance across the site in meters, and the y-axis shows elevation in meters. The approximate depth of penetration at the site is 10 meters. The points where the profiles intersect each other are also labeled on the figures. To emphasize the contrasts in the resistivities the EM34 profile data were plotted using the log-base-10 of the resistivity values.

Ground conductivity measurements are primarily influenced by soil/sediment type, proximity of bedrock to the ground surface, moisture content, and water chemistry. Clayey materials, saturated sediments, and saline groundwater are generally more conductive, while sandy, dry materials, unaltered bedrock, and freshwater are generally more resistive. The EM data suggests a 3-layer model of resistivities at the site. The uppermost layer includes the near surface sandy sediments and is identified on the EM profiles by the red, orange, and yellow contours. The second layer, identified by the green contours, is more conductive and probably represents silty- or clayey-sand sediments. The bottommost layer, identified by the blue and purple contours, is very conductive. The resistivity values for this layer are so low as to suggest that the sediments, which may be dredge sediments, are saturated with salt water.

A resistive EM anomaly is evident along Line 3 (Figure 11) between 479640 – 479740 meters (UTM x-coordinate), and may extend to 479800 meters. The location of this anomaly is adjacent to the suspected western boundary of a river channel that previously bisected the site. It is possible that this resistive anomaly could represent a fresh water intrusion into the conductive media that surrounds it in the EM profile. Another possibility is that clean sands extend to depth at this location. The resistivity values of EM anomaly on Line 3 are not unreasonable for clean sand and/or fresh water. This anomalous zone along profile 3 may warrant further investigation.

4. REFERENCES

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Dobrin, M.B., introduction to Geophysical Prospectihg: McGraw-Hill, New York, 1960.

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Parasnis, D.S., Principles of Applied Geophysics : John Wiley and Sons, New York, 1962.

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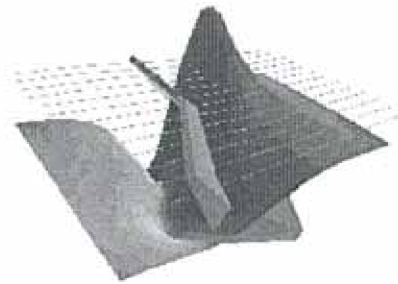
APPENDIX A

EM34 Ground Conductivity Data Processing

EM34 Processing in EMIGMA
Friday, July 9, 2004

Ross W. Groom, PhD
PetRos EiKon Incorporated
Concord, ON, Canada



Stage 1: Basic Processing

Initial *.r34 supplied from data logger in ASCII/Binary format are converted via Geonics's format to instrument dependent ASCII format - *.G34. The *.g34 format contains the data for each "pull" or instrument separation sampled at approximately 4Hz with each data stamped with GPS time. The *.g34 file also contains data positioning sampled at approximately 1Hz with positioning given in Latitude/Longitude.

The first stage is to read the *.g34 files and convert Lat/Long to UTM using WGS84 datum and standard projections. During this stage, the location of each datum is determined via interpolation of UTM's from GPS time information. Adjustment of location is made at this stage, locally, for GPS antennae location versus TX. Geonics also provides software to provide the projections but the output format while giving the UTM's is not suitable for our use. We did, however, check the consistency of our projections with the Geonics projections and were satisfied with the accuracy.

At this point, the data is now imported pull-by-pull and line-by-line into our database product, EMIGMA, for the remainder of the processing and interpretation.

Stage 2: Data Examination, Editing and Integration

Upon input of a particular pull for a certain line, the data positioning is first analysed with a visual tools, which shows the track of the data line and individual data positioning. Bad data points are now either removed or corrected. Significant data are removed from the ends of the line due to erratic positioning at the beginnings and ends of each pull. The data is now examined and any obvious "bad" data is removed. The position of the data is now shifted to be represented at the centre between the transmitter and the receiver for that pull.

The above steps are repeated for the same separation for all 3 lines and then the 3 lines merged for analyses. Data positioning and data consistency was then analysed for all 3 lines for each separation.

After these processes were confirmed for all 3 separations, the 3 data were then merged.

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Stage 3: Data Merging, Editing and Filtering

The data was merged by making the union of all data points with a tolerance of .2m used to identify identical points. As the 3 separations were collected independently the data for each separation was generally at a different set of locations with virtually no common points.

Thus, in the union of the data locum each data point would have data for only one separation. The data was then interpolated so that each data point at data for all 3 locations. The interpolation was checked against the original data to ensure this interpolation maintained the detail of the raw data.

The new set of data locations was necessarily very ragged locally due to data locations of each pull being close to each other but not exactly the same. The data locations were then smoother through interpolation techniques to make a smooth data line that lay between the loci of the total data point set.

At this stage, the data was then examined more thoroughly comparing the data for all 3 separations. As the data was to be imaged (interpolated) via stacked 1D inversions, it was necessary to remove data where there were obvious three-dimensional effects. (The three dimensional effects can be imaged through modelling but there was insufficient time in the contract to perform this work.). In particular, Line 1 had a large 3D response over much of the southern part of the line, which was removed.

At this stage, the data has roughly 3 times the original data density. A moving Gaussian averaging filter then decimates the data. The filter has several advantages improving signal/noise characteristics and reducing small-scale 3D effects in the data. The technique was simultaneously performed also on the GPS altitude data. This improved considerably the jitter in the GPS-Z information.

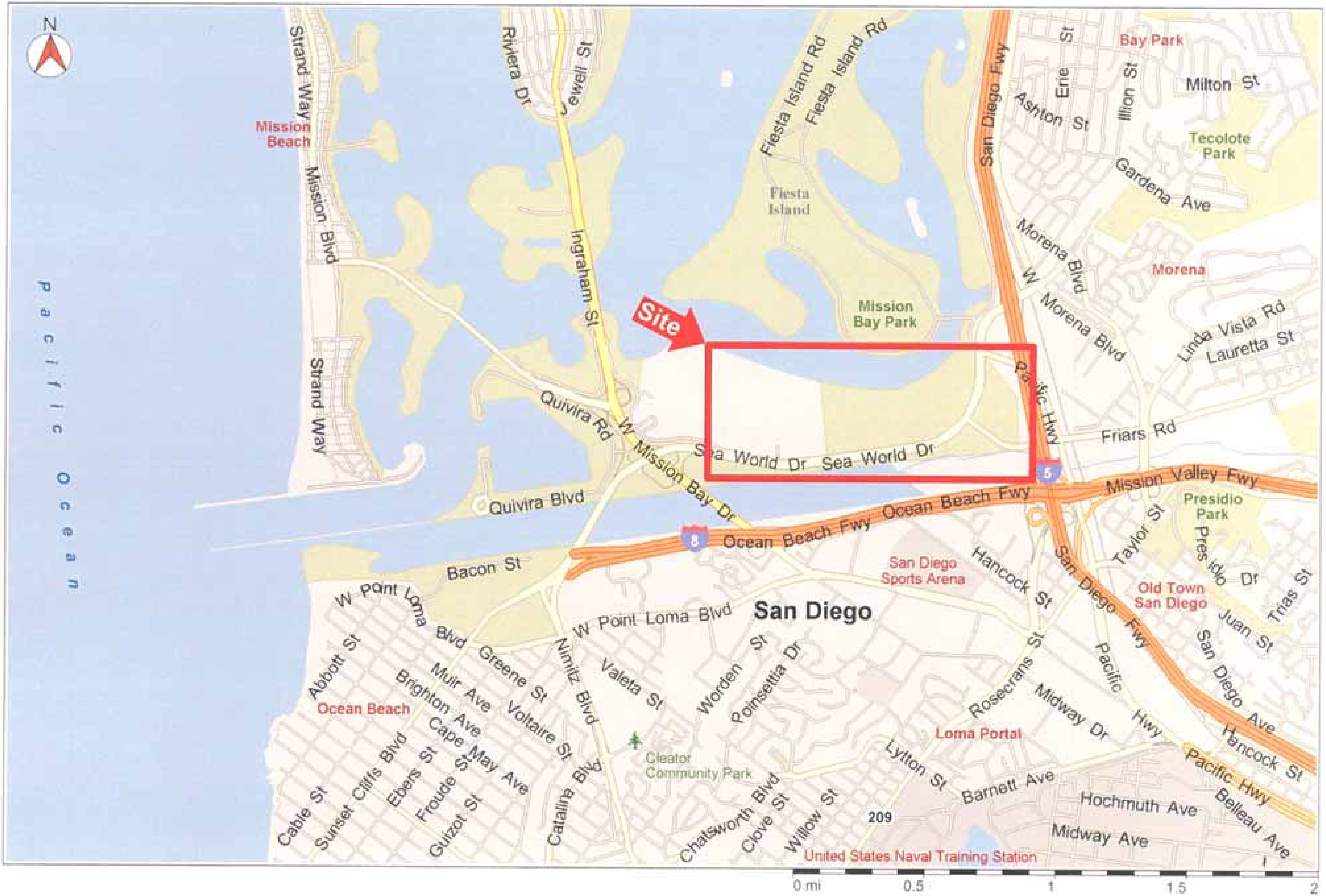
The data at this stage is now 3/5 of the original data density. The processed data was now compared, in detail, to the raw data to ensure data reliability and consistency with the original data and to ensure no important features are lost. At this stage, the data was decimated one more time in the same manner but ensuring that no imageable features were lost. This last decimation improved again signal/noise and non-3D effects in the data while reducing the amount of time for processing and imaging.

Stage 4: Conductivity-Depth Imaging:

Forward modelling exercises were now performed and compared to the data to ensure data consistency and to understand the basic gross structural model under the three lines. Conductivity-Depth images were now performed on the data. These images are performed by data inversion, which utilizes techniques to find the best 1D model for the 3 data under each resulting data point. Two techniques were performed, Occam and Marquardt techniques. The Occam technique utilizes more parameters in the model than there is data and provides a smooth, good fitting but fuzzy ground model. It does, however, generate a rough idea of the ground. The Marquardt technique utilizes either 3 or 4 layers in the model but several of the parameters are constrained by information determined by the forward modelling exercise and the Occam inversions. The models are not so well fitting are sharper but provide better resolution assuming the constrained parameters are correct.

The resulting conductivity-depth images are then processed to a regular grid (Position vs. Depth) and corrected for GPS elevation.

FIGURES



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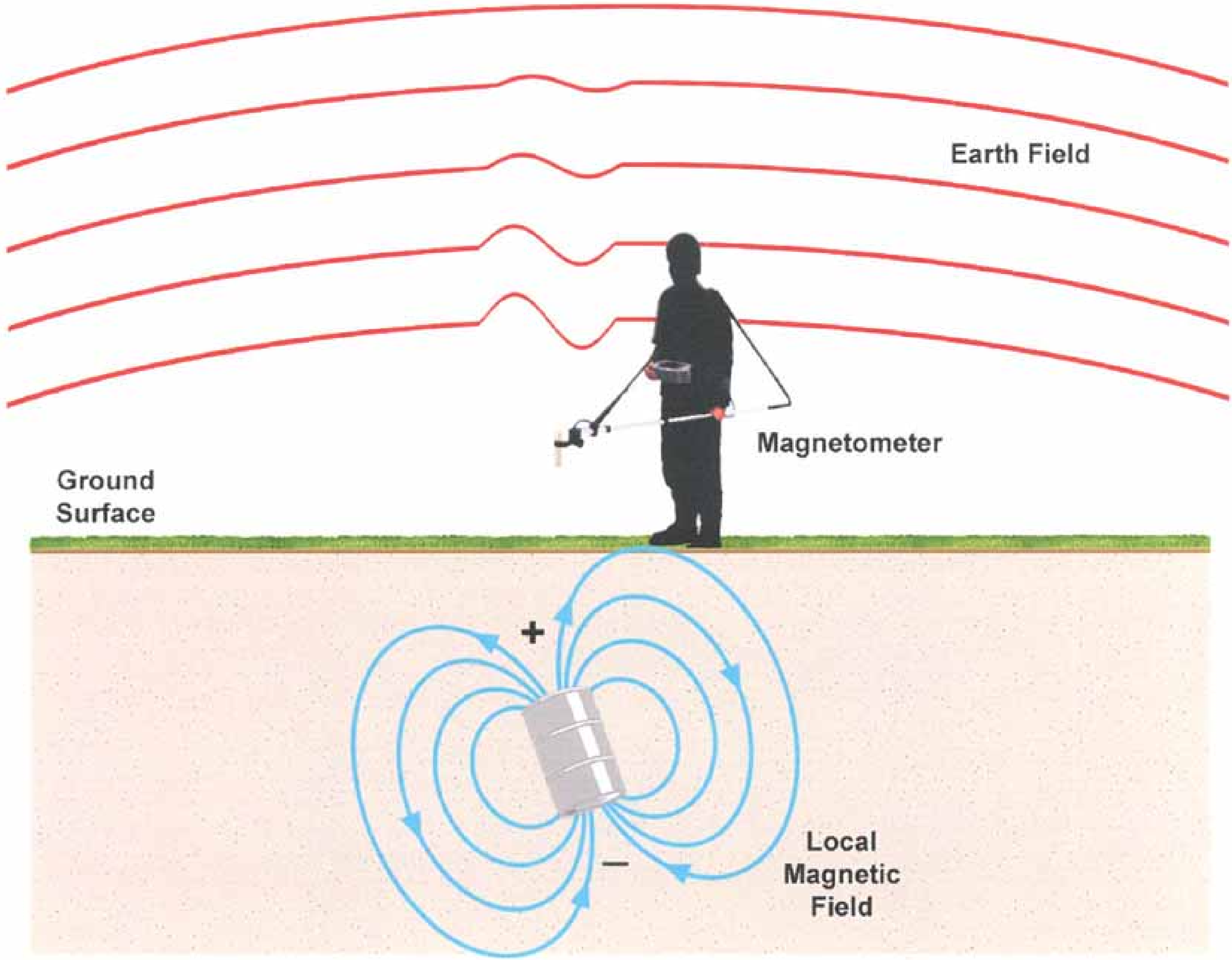
Title

Mission Bay Landfill Site Location

Reference

Figure No.
1

3Dgeophysics.com 721 3rd Avenue Mendota Heights, MN 55118 Tel. (651) 450-1850 • Fax: (651) 450-1851	Title Geophysical Survey Locations	Reference March 2002 aerial photograph provided by SCS	Figure No. 2



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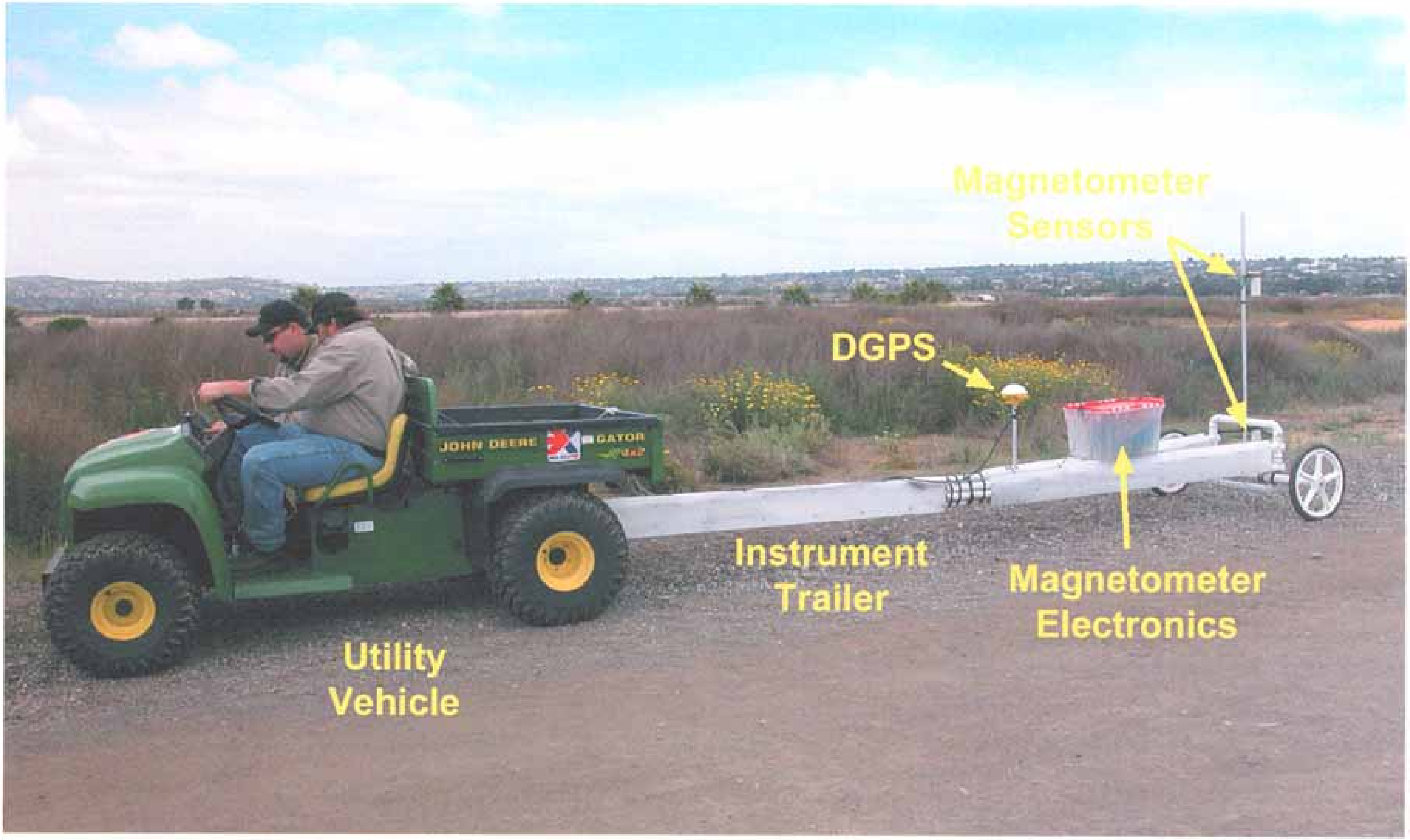

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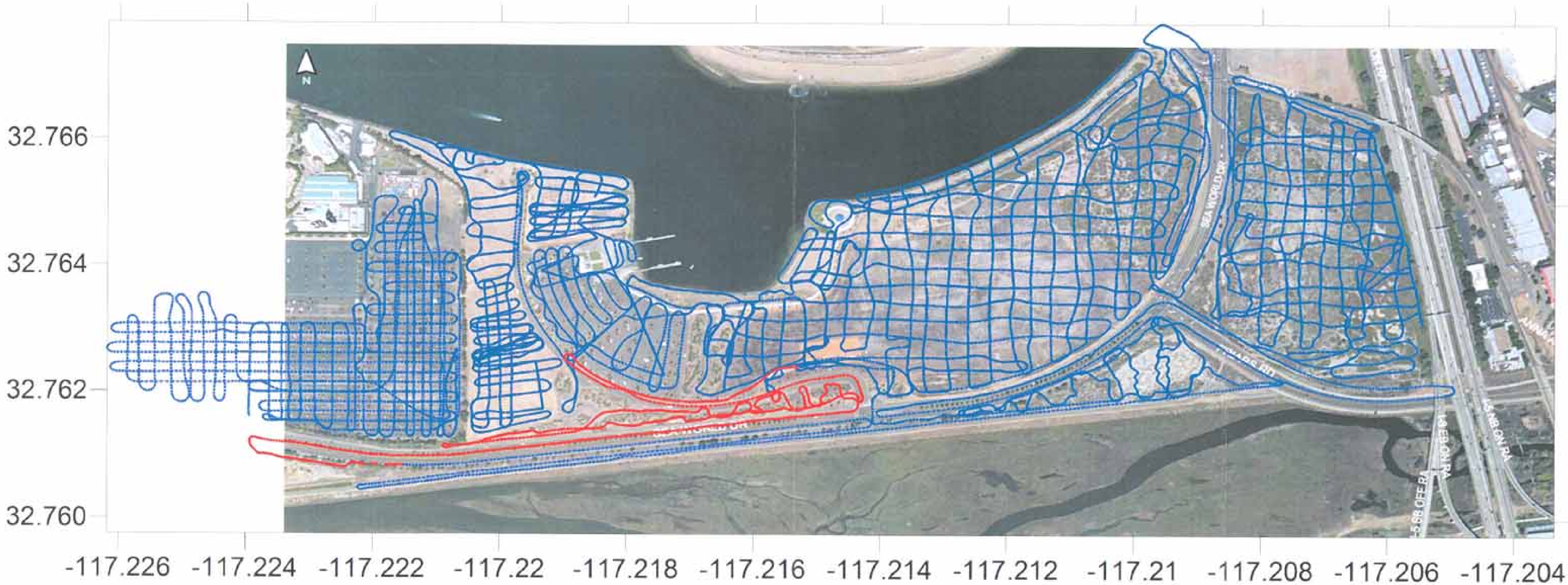
Title	Reference	Figure No
Field Photograph: Magnetometry Survey Equipment		4

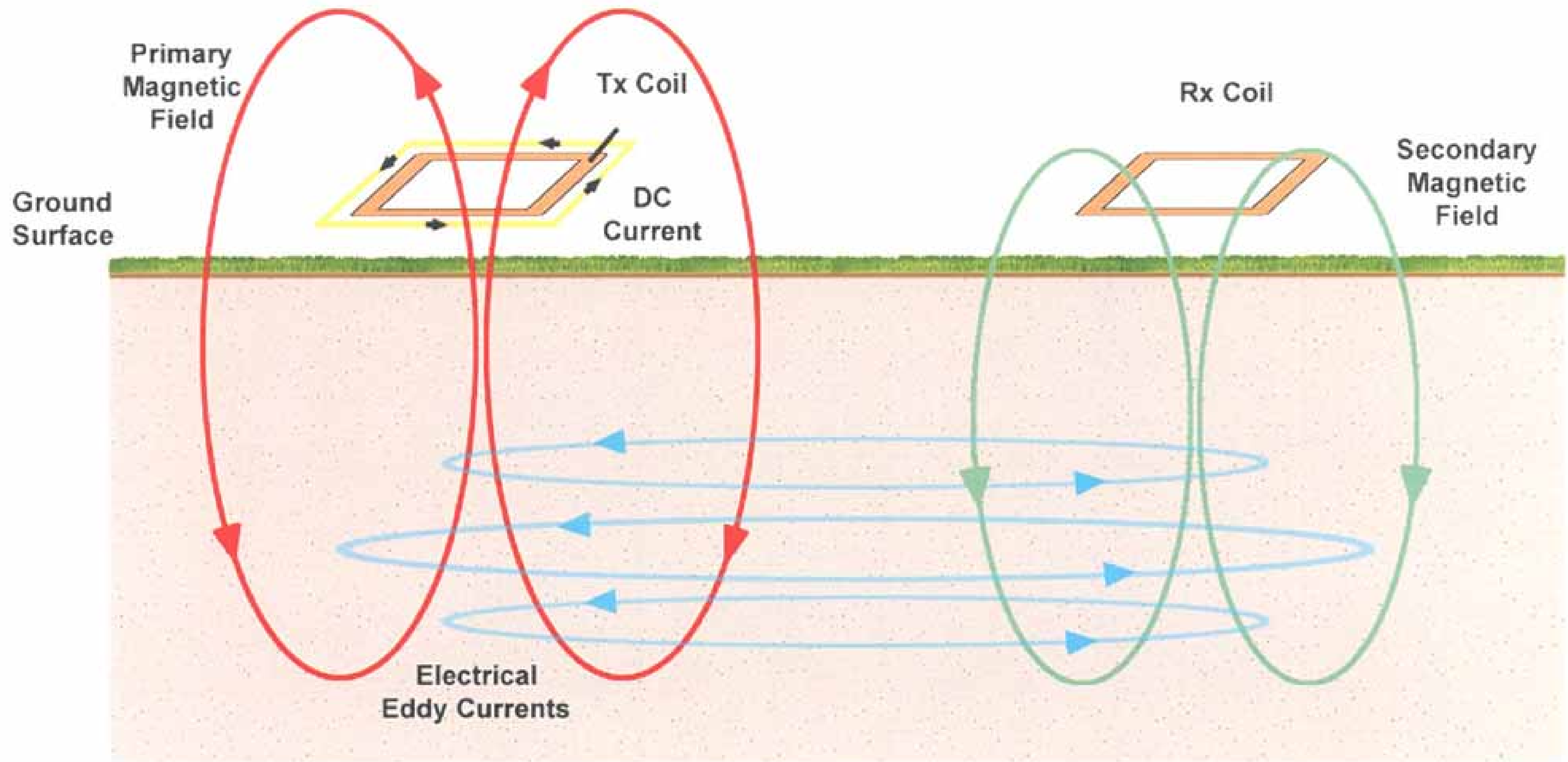


Coordinates: decimal degrees

+ Gradient Field

+ Normalized Total Field

3Dgeophysics.com 721 3rd Avenue Mendota Heights, MN 55118 Tel (651) 450-1850 • Fax (651) 450-1851	Title Magnetic Data Coverage Map	Reference March 2002 aerial photograph provided by SCS	Figure No. 5



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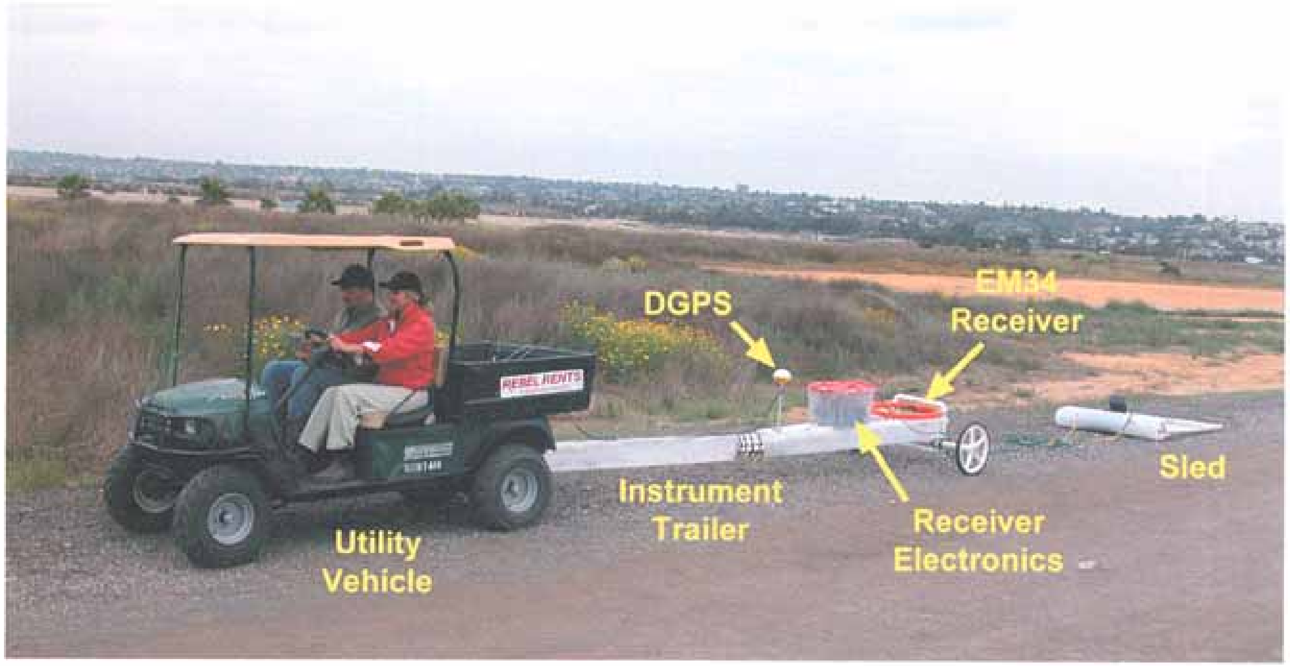
Title	Reference	Figure No
Ground Conductivity Surveying Schematic		6



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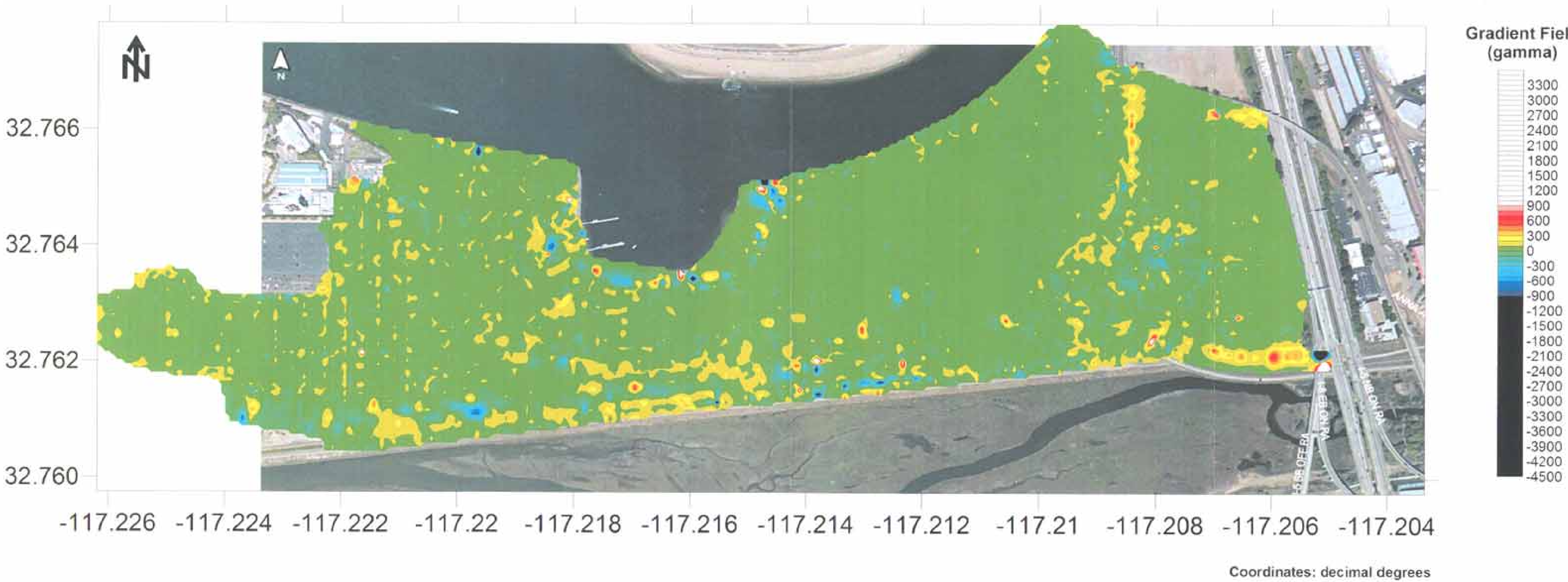
Title

Field Photographs: Ground Conductivity Survey Equipment

Reference

Figure No
7



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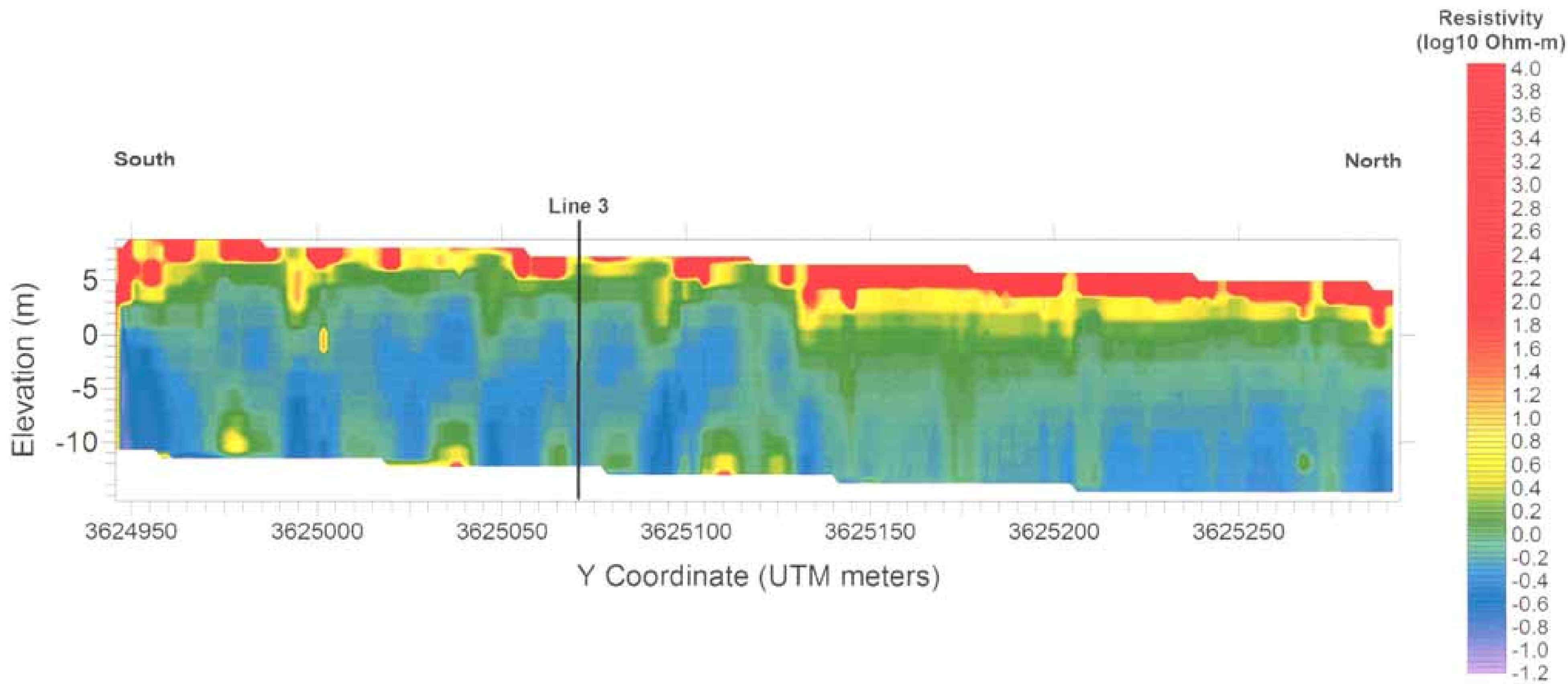

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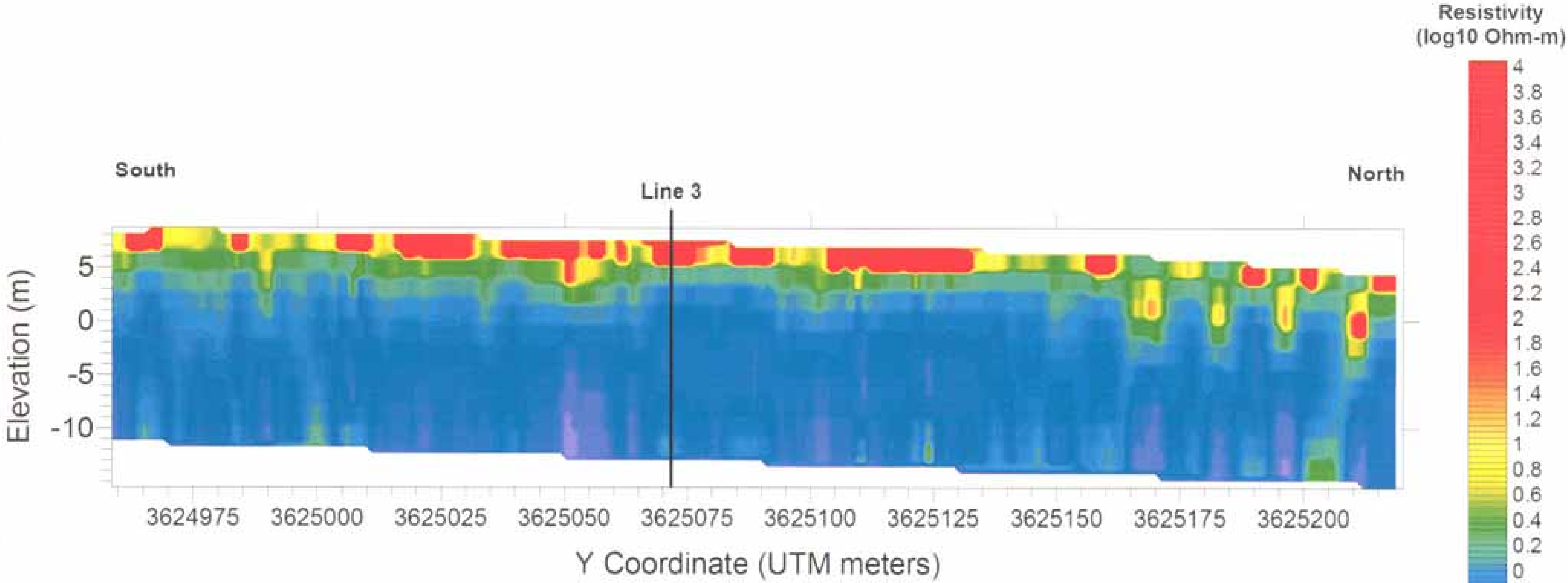
Title

EM34 Profile - Line 1

Reference

Figure No.
9



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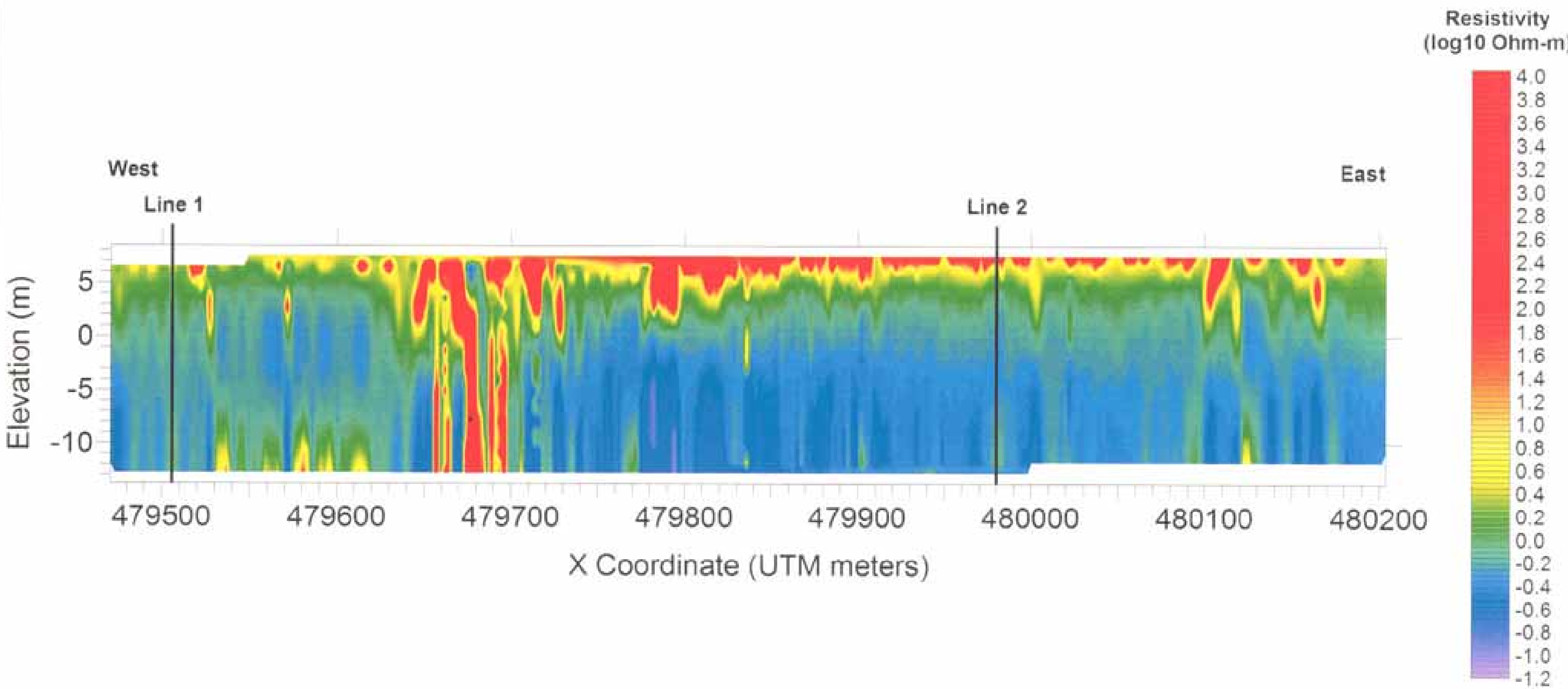

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Title

EM34 Profile - Line 3

Reference

Figure No
11